

1 "ROTATIONAL IMPACT DRILL ASSEMBLY"

2
3 FIELD OF THE INVENTION

4 91) The present invention relates to rotary impact, torque intensifying
5 apparatus for use with drill bits, particularly PDC bits and methods of use applied to
6 subterranean drilling.

7
8 BACKGROUND OF THE INVENTION

9 Conventional drill bits include roller bits which use compression to
10 crush rock at the toolface when drilling a wellbore in a subterranean formation. It is
11 known to apply axial impact assemblies for enhancing the compressive breaking
12 action of percussive bits.

13 PDC bits, however, use a shearing action to break the material of the
14 formation. Excessive axial force on a PDC bit is a known cause of failure of the
15 cutters.

16 The PDC cutters and inserts of PDC bits are subject to failure through
17 vibration and impact. Ideally, a PDC bit has continuous loading while shearing
18 material at the toolface. However, when the rate of penetration suddenly slows, or
19 when a hard interface is encountered, such as a stringer, the bit slows or hangs up,
20 possibly even temporarily ceasing to rotate. Despite slowing or cessation of rotation
21 of the drill bit, the drill string continues to rotate. Whether the bit is at the end of a
22 rotating drill string, or at the end of a coiled tubing BHA, the rotary drive continues to

1 wind up the drill string, building up torque and potential energy. Typically, the torque
2 reaches a certain elevated level and the bit finally releases and spins violently, either
3 due to the energy built up or due to a shortening of the drill string as it winds up.
4 The sustained release of energy as the bit spins causes chatter or repeated impacts
5 of the PDC cutters against the rock face - causing significant damage to the PDC bit
6 cutters.

7 ~~It is an expensive process to trip out and replace and replace a~~
8 ~~damaged PDC bit.~~

9 It is believed that PDC bit failure is caused by the chatter and impact
10 associated with the sustained and violent release of the built up torque.
11 Nevertheless, the lock up of a PDC bit is a known and persistent problem resulting in
12 expensive down time and equipment cost

14 SUMMARY OF THE INVENTION

15 In a surprising discovery, PDC bit performance is improved and
16 incidences of failure can be reduced by repeatedly applying increased torque at the
17 PDC bit through the use of a rotary impact tool. So as to avoid large build up of
18 torque and to suffer the associated sustained impact damage to a PDC bit on
19 release, an assembly is provided for introducing a consistent series of smaller and
20 localized rotary impacts to the bit, avoiding lockup and potentially damaging energy
21 storage in the drill string.

1 The present invention implements a method and apparatus for
2 increasing the drilling effectiveness of PDC bits while minimizing failures due to the
3 release of energy following windup.

4 Simply, the method comprises increasing the effective torque of the
5 drill bit by repeatedly and periodically intensifying the torque at the PDC drill bit. The
6 periodic increases in torque avoid the potential for build-up of torque on bit lockup or
7 sustained high torque incidences which are associated with PDC bit failure when the
8 built-up of torque is released. Preferably, introduction of rotary impact is applied
9 only during drilling.

10 In an apparatus aspect, a rotary torque impacting assembly is
11 positioned between the drill bit and the rotary drive such as a rotary drill string or a
12 downhole motor. The drill bit is adapted for rotation by the assembly which provides
13 the nominal torque necessary to develop the shear forces used by the PDC bit to cut
14 the formation. An energy source in the impacting assembly supplements the
15 nominal torque provided by the rotary drive. Preferably, a drilling fluid driven turbine
16 in the assembly drives a rotary hammer for periodic impacts with an anvil connected
17 through to the drill bit.

18 The assembly comprises an output bit shaft for connection to the drill
19 bit, and a housing for connection to the rotary drive. The bit shaft has a lower
20 connection to the bit and an upper shaft end which projects into the downhole end of
21 the housing and is rotatably driven thereby. The upper shaft end is fitted with a
22 rotary anvil. The housing further houses a motor which rotates a hammer about the

1 bit shaft's anvil. The motor spins the hammer and builds up its potential energy.
2 When the anvil and hammer connect, the potential energy is released into the upper
3 shaft end and thus into the drill bit, increasing its instantaneous torque and hence to
4 cut through the difficult formation. For increased effectiveness, the bit shaft is
5 adapted for permitting limited rotational freedom relative to the driving housing so
6 that the bit shaft receives substantially all of the rotary impact. Preferably, the
7 hammer's motor is impeded from operation when the bit is off bottom and not
8 drilling.

9 10 BRIEF DESCRIPTION OF THE DRAWINGS

11 Figure 1 is a cross-sectional view of one embodiment of a rotary
12 impact assembly of the present invention;

13 Figures 2a and 2b are cross-sectional views of the rotary impact
14 assembly of Fig. 1;

15 Figure 2a illustrates the assembly when the bit shaft is off bottom so
16 that the rotary drive is rotationally restrained;

17 Figure 2b illustrates the assembly when the bit shaft is on bottom so
18 that the rotary drive is free to rotate and impart rotational impact into bit shaft;

19 Figure 3a is a cross-sectional view of the housing and bit shaft
20 interlocking castled interface during drilling operations prior to impact according to
21 Fig. 2b;

Figure 3b is a partial cross-sectional view of the housing and bit shaft of Fig. 3a immediately after impact of the hammer and anvil;

Figure 4a is a partial cross-sectional view of the hammer carrier, hammer and anvil of the assembly according to Fig. 2b;

Figure 4b is a cross-sectional view of the carrier according to the section S-S of Fig. 4a, illustrating the hammer in full rotation prior to impacting the anvil;

Figure 4c is a cross-sectional view of the carrier of Fig. 4b at impact of the hammer and anvil; and

Figures 5a – 5h are sectional views according to section S-S of Fig. 4a, illustrating the hammer, hammer carrier and anvil of the assembly and sequential views of the transfer of rotational impact energy from impact through to release of the hammer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Having reference to Fig. 1, a rotary impact tool of the present invention comprises an assembly 10 which is positioned between a rotary drive such as a rotary drill string or a downhole motor (not shown) and drill bit (not shown). The drill bit is typically employed to drill a wellbore through material in a subterranean formation. The assembly 10 comprises a driving housing 11 having a bore 12 and which is adapted for connection at a first end 13 to the rotary drive and at a second end 14 to a bit shaft 15 extending from the bore 12. The bit shaft 15 has a downhole

1 end 16 which is adapted for connection to a drill bit, such as a bit fitted with PDC
2 cutters. The bit shaft 15 is fitted to the housing 11 so that rotation of the drive
3 housing 11 also rotates the bit shaft 15. Such co-rotation is achieved using a spline
4 arrangement or interlocking castling 17 between the housing's end 14 and the bit
5 shaft 15. A rotary impact assembly 20 is fitted into the housing's bore 12.

6 In one embodiment of an impact assembly 20, depicted in Fig. 1, the
7 assembly 20 comprises a turbine motor 21 which provides the impetus for rotating a
8 mass and storing potential energy. The turbine motor 21 is located within the bore
9 12 and is supported on a stator shaft 22 guided at an upper bearing 23 and at a
10 lower bearing 24. The stator shaft 22 is enlarged at its lower end 25 for forming a
11 hammer carrier 30 having a concentric cavity 31 formed therein. The carrier cavity
12 31 encircles an uphole end 32 of the bit shaft 15.

13 Having reference also to Figs. 4a – 4c, the bit shaft's uphole end 32
14 has a radially outwardly projecting dog or anvil 33.

15 When the stator shaft 22 rotates, periodically, the rotating hammer 35
16 and the bit shaft's anvil 33 are coupled to impact and impart the potential energy of
17 the moving hammer into the bit shaft.

18 The carrier 30 is fitted with an annular mass 34 having a radially
19 inward projecting dog or hammer 35. The annular mass 34 is pivotable about a first
20 pin 36 fitted to the carrier 30 at a tangent of the annular mass 34. The annular mass
21 34 has a first circular notch 37 at its tangent, the notch 37 being dimensionally sized

1 so as to be pivotable about the first pin 36 and thereby permitting the annular mass
2 34 to move between concentric and eccentric positions about the bit shaft.

3 Diametrically opposite the first pin 36 is a second pin 38 secured in the
4 carrier 30. A second elongated notch 39 is formed in the annular mass 34,
5 diametrically opposite the first notch 37. The second notch 39 is elongated
6 circumferentially and, forming stops spaced at about the same angular dimension as
7 the length of the radially inward projection of the hammer 35. The second notch 39
8 is sized so that the annular mass's extreme eccentric position, the hammer 35
9 decouples or is released from the bit shaft's anvil.

10 Returning to Figs. 1, 2a and 2b, the turbine motor 20 comprises a
11 plurality of turbines 40 affixed to and spaced axially along the stator shaft 22. Each
12 turbine 40 occupies an annular space 41 in the bore 12, formed between the stator
13 shaft 22 and the housing 11. A plurality of complementary diffusers 42 are
14 arranged, one per turbine 40 and are affixed in the annular space 41. Five turbines
15 and four diffusers are shown.

16 A flow path is formed through the housing 11 and bit shaft 15 for
17 conducting drilling fluids through the assembly 10 and to the bit. Drilling fluid flows
18 into the assembly 10 from the rotary drive and into the bore 12 of the housing 11.
19 Fluid then flows through the annular space 41 housing the diffusers 42 and turbines
20 40. Ports 43 are formed in the stator shaft 22 above the carrier 30 and conduct the
21 drilling fluids from the turbines' annular space 41 and centrally into a bore 44 formed

1 in the stator shaft 22. The bore 44 in the stator shaft 22 is contiguous with a bore 45
2 formed in the bit shaft 15 for conducting drilling fluid to the bit.

3 In an optional embodiment, it is advantageous to minimize assembly
4 component wear by limiting the rotary impact operation to the actual drilling
5 operations. There is little advantage in having the rotary impact operation occurring
6 during running in and tripping out of the drill string. Accordingly, an arrangement is
7 provided for arresting rotation of the turbine motor 20 until such time as the drill bit is
8 on bottom of the drilled wellbore.

9 Having reference to Figs. 2a and 2b, the bit shaft 15 has limited axial
10 movement responsive to weight on bit such as when contacted on the bottom of the
11 wellbore being drilled. As shown in Fig. 2a, when off bottom, the bit shaft 15 is
12 biased downwardly, binding the turbine motor 20 against rotation. In Fig. 2b, when
13 on bottom, the bit shaft 15 is forced uphole which releases the turbine motor 20 for
14 rotation.

15 Referring to Fig. 2a, while the bit shaft is not drilling and off bottom, an
16 annular spring 50 biases the bit shaft 15 downhole. The spring 50 acts between an
17 annular stop 51 and a shoulder 52 on the bit shaft 15. A cap 53 threaded onto the
18 uphole end 32 of the bit shaft 15 has a base 54 which engages a shoulder 55 on the
19 carrier 30, also biasing the stator shaft 22 downhole. When biased downhole, each
20 turbine 40 shifts freely and axially within the annular space 41 and within an axial
21 tolerance provided between diffusers 42. At the top of the stator shaft 22, a capping
22 nut 57 moves axially downhole with the stator shaft 22 and engages a braking

1 surface or frictional interface 58. Even through the shaft 22 is frictionally restrained,
2 drilling fluid can continue to flow substantially unimpeded through the turbines 40
3 and through to the bit shaft 15 and bit.

4 Referring to Fig. 2b, when the bit shaft 15 is on bottom and drilling, the
5 reactive force F overcomes the spring 50 and shifts the bit shaft 15 axially uphole. A
6 thrust bearing 60 is fitted to the top of the cap 53. A complementary thrust bearing
7 61 is fitted into the carrier cavity 31. One suitable set of bearings 60,61 include
8 facing PDC surfaces. The uphole axial shift of the bit shaft 15 also drives the carrier
9 30 and stator shaft 22 uphole, lifting and disengaging the capping nut 57 from the
10 frictional braking surface 58, freeing the stator shaft 22 for rotation when drilling
11 fluids flow through the turbines 40 and diffusers 42, and initiating rotary impact
12 operation.

13 Having reference to Figs. 4a-4c and Figs. 5a-5h, in operation, the
14 rotating stator shaft 22 rotates the carrier 30 and annular mass 34 (Fig. 4b). Each
15 revolution of the stator shaft 22 brings the hammer 35 into impact contact with the bit
16 shaft's anvil 33 (Fig. 4c) for periodically and rotatably impacting the bit shaft 15 for
17 intensifying the torque applied to the drill bit. Each impact converts the potential
18 energy of the rotating annular mass 34 into increased torque. The momentum of the
19 annular mass 34 is transferred into the bit shaft 15 and the bit, briefly yet
20 energetically aiding in bit rotation despite resistance encountered by the bit.

21 In repeated and periodic cycles, and having reference to Figs. 5a – 5h,
22 after each impact, the annular hammer 35 is able to recover and rotate once again

1 to raise its potential energy for the next impact. Despite the periodic impact which,
2 for each cycle, arrests the annular hammer's rotation, the hammer 35 is caused to
3 disengage from the anvil 33 and begin the annular mass's cycle of rotation once
4 again.

5 In Fig. 5a, in a first step of the cycle, the impact of hammer and anvils
6 35,33 is depicted. In Fig. 5b, the energy of the impact causes the annular hammer
7 35 to begins to pivot about the first pin 36 . As shown in Figs. 5c – 5f, the annular
8 hammer 35 continues to pivot about the first pin 36, enabled by a shifting of the
9 elongated second notch 39 along the second pin 38, permitting pivoting to continue
10 unchecked. The center of the annular hammer 35 progressively shift so that
11 eventually the hammer and anvils 35,33 separate radially. As shown at Fig. 5h, at
12 the end of the impact cycle, the hammer and anvils 35,33 have fully disengaged and
13 the turbine motor 30 is free once again to rotate the annular hammer 35 through the
14 next rotation to initiate the next impact cycle.

15 Having reference to Figs. 2a, 3a and 3b, the energy released into the
16 bit shaft 15 is most effective if it is directed substantially entirely into the materials
17 being drilled. The least effective energy transfer is that which is imparted and
18 absorbed by the mass of the entire drill string. Accordingly, the bit shaft 15 is
19 partially decoupled rotationally from the housing 11 for permitting limited rotational
20 freedom. As shown on Fig. 2a, the bit shaft 15 forms a shoulder 63 at the interface
21 of the bit shaft 15 to an end face 65 of the housing 11. This housing end face 65

1 and bit shaft shoulder 63 interface is fitted with complementary castled faces of
2 alternating axially projecting dogs.

3 Turning to Fig. 3a and 3b, in one embodiment, four axial bit shaft dogs
4 66, each having a 45° arc, are circumferentially spaced on the bit shaft shoulder
5 forming four annular gaps 67 of about 45° each. Four corresponding axial housing
6 dogs 68, each having a 40° arc, are also circumferentially spaced on the housing's
7 end face 65 forming four annular gaps 69 of about 50° each. When drilling, the 40°
8 housing dogs 68 advance to engage the bit shaft's 45° annular gaps.
9 Correspondingly, the 45° bit shaft dogs 66 advance to engage the housing's 50°
10 annular gaps 69. The housing's bit shaft dogs 68 rotationally drive the bit shaft 15
11 which drives the bit to drill. Accordingly, the bit shaft 15 has a limited independent
12 rotational capability.

13 Each impact of the hammer and anvils 35,33 causes the bit shaft 15 to
14 be driven momentarily and rotationally ahead of the housing's rotation, the bit shaft
15 shoulder dogs 66 advancing ahead of the housing's dogs 68 so as to absorb
16 substantially all of the energy in the annular hammer 34 and imparting it into the drill
17 bit without involving the assembly or the drill string.